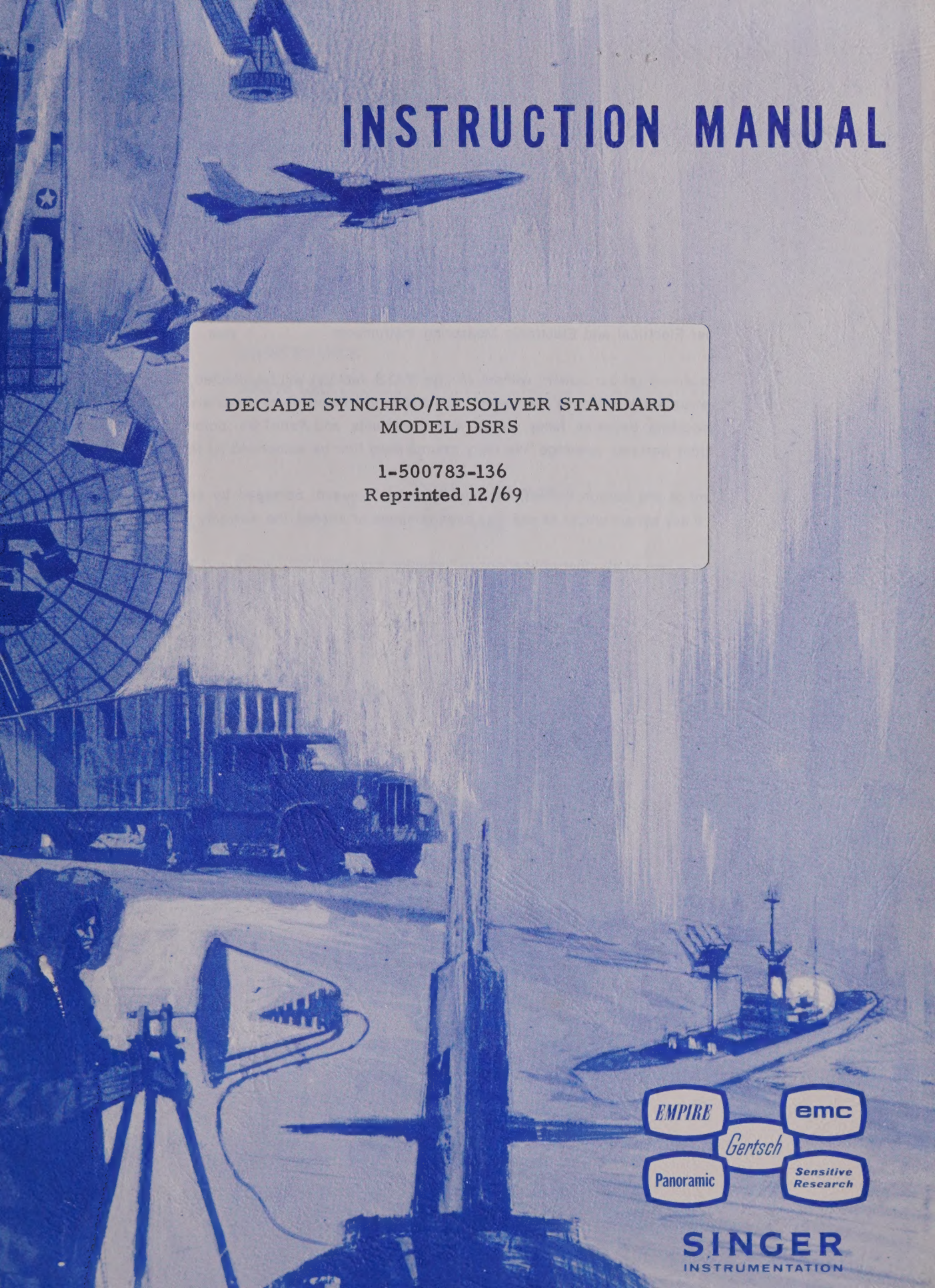


INSTRUCTION MANUAL

DECADE SYNCHRO/RESOLVER STANDARD
MODEL DSRS

1-500783-136
Reprinted 12/69

EMPIRE emc Gertsch Panoramic Sensitive Research

SINGER
INSTRUMENTATION

INSTRUCTION MANUAL

DECADE SYNCHRO/RESOLVER STANDARD
MODEL DSRS

1-500783-136
Reprinted 12/69

WARRANTY

THE SINGER COMPANY, INSTRUMENTATION DIVISION, warrants each new instrument to be free from defects in material and workmanship, effective after delivery to the original purchaser as follows:

Sensitive Research Electrical Indicating Instruments.....2 years
Other Electrical and Electronic Measuring Instruments.....1 year

Repair or replacement (at our option) without charge (F.O.B. factory) will be effected when our examination satisfactorily indicates that defects are due to workmanship or materials. Electron tubes, semiconductors, batteries, fuses, lamps, thermoelements, and *RatioTran* potentiometers are excluded from warranty coverage. Warranty returns must first be authorized by the factory.

If the instrument or any portion thereof, has been abused, misused, damaged by accident or negligence, or if any serial number or seal has been removed or altered, the warranty is void.

This warranty is in lieu of all other obligations or liabilities expressed or implied and The Singer Company neither assumes, nor authorizes any person to assume for them, any other liability in connection with sales of instruments manufactured by The Singer Company, Instrumentation Division.

THE SINGER COMPANY • INSTRUMENTATION DIVISION
HOME OFFICE: 915 PEMBROKE STREET, BRIDGEPORT, CONNECTICUT

REPAIR AND MAINTENANCE

Instruments should be returned only on prior written authorization from the Singer Representative or the factory(1). Warranty repair will be made upon written request. Please provide the following information in order to expedite our processing of your instrument:

1. Model or Type
2. Serial Number
3. Description of trouble(2)
4. Test instruments used
5. Approximate date instrument was placed in operation
6. Approximate number of hours of use
7. Has maintenance action been previously requested?
8. Other comments

Upon receipt of this information our Service Department will send you service data or shipping instructions. Upon receipt of shipping instructions forward the instrument to the factory prepaid. If requested, an estimate of charges will be made before work begins.

(1) Contact Instrumentation Division, 915 Pembroke St., Bridgeport, Connecticut for *Empire, Panoramic, Ballantine* and *Sensitive Research* instruments. Contact Instrumentation Division, 3211 S. LaCienega Blvd., Los Angeles, California for *Gertsch* and *EMC* instruments.

(2) Include data on symptoms, measurements taken, suspected location of trouble, maintenance action taken, and any other relevant data.

TABLE OF CONTENTS

Section		Page
I	GENERAL DESCRIPTION	1-1
II	INSTALLATION	2-1
III	OPERATION	3-1
IV	THEORY OF OPERATION	4-1
V	MAINTENANCE	5-1
VI	PARTS LIST	6-1

LIST OF TABLES

Table	Title	Page
1-1	Specifications	1-1
3-1	Binding Post Identifications, Synchro Mode	3-1
5-1	Angular Accuracy, Resolver Mode	5-2
5-2	Angular Accuracy, Decade Increments, Resolver Mode	5-4
5-3	Angular Accuracy, Synchro Mode	5-4
5-4	Angular Accuracy, Degrees, Minutes, Seconds Increments	5-5/5-6

LIST OF ILLUSTRATIONS

Figure	Title	Page
1-1	Model DSRS Decade Synchro/Resolver Standard	ii
1-2	Typical Test Setup, Synchro Mode	1-2
1-3	Typical Test Setup, Resolver Mode	1-2
4-1	Simplified Diagram, Resolver Mode	4-2
4-2	Standard Synchro Control Transmitter (CX) Outputs	4-3
4-3	Simplified Diagram, Synchro Mode	4-3
4-4	Model DSRS-3R Schematic Diagram	4-4
4-5	Model DSRS-5R and DSRS-6R Schematic Diagram	4-5
4-6	Model DSRS-5DR Schematic Diagram	4-6
4-7	Model DSR -7R Schematic Diagram	4-7
5-1	Angular Accuracy Test Setup, Resolver Mode	5-2
5-2	Angular Accuracy Test Setup, Synchro Mode	5-3

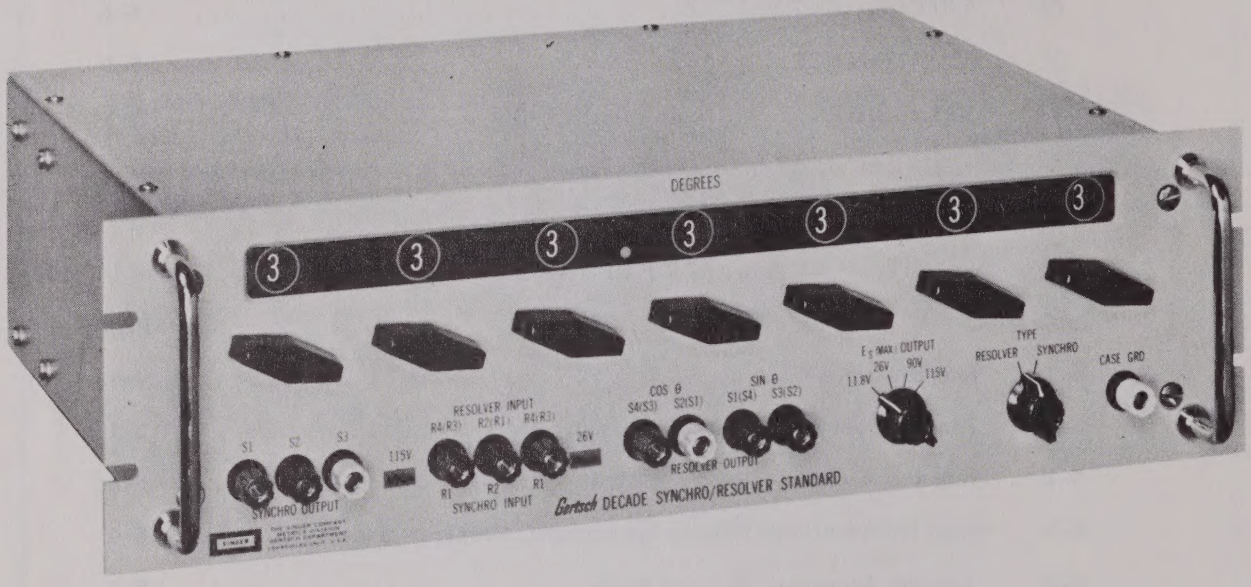


Figure 1-1. Model DSRS-5DR Decade Synchro/Resolver Standard

SECTION I
GENERAL DESCRIPTION

1-1. PURPOSE.

1-2. The Model DSRS combines the functions of a decade synchro standard and a decade resolver standard into a single unit. A front panel switch changes the unit from one mode to another.

1-3. The standard may be used to simulate a master component in a system. Accurately known inputs may be introduced into the system for testing autopilots, servos, aircraft indicators, etc. This technique can also be used to check the response of a servo loop.

1-4. As a synchro standard, the unit may be used to transmit precise angular data to control differential transmitters (CDX's) and control transformers (CT's) (see figure 1-2). Most commercially available synchros of this type may be excited without affecting the 2-second-of-arc accuracy. The unit may also be used to excite torque differential transmitters (TDX's), differential receivers (TDR's), and receivers (TR's).

1-5. As a resolver standard, the unit may be used to transmit precise angular data to resolver control differential transmitters (RD's) and resolver control transformers (RC's). As with the synchro mode, most commercially available resolvers may be excited without affecting the 2-second-of-arc accuracy.

1-6. When the Model DSRS is used for testing components, either the Proportional Voltage Gradient or the Proportional Voltage Nulling method may be used. If the Proportional Voltage Nulling method is used, the Model DSRS may be adjusted to obtain a null instead of the dividing head. In this case, the angular error may be read directly from setting of the control switches.

1-7. GENERAL DESCRIPTION.

1-8. RESOLVER MODE. The unit forms a precision transformer instrument, designed to simulate the ideal electrical outputs of a resolver control transmitter (RX). Each section transforms an input signal to two isolated voltages: one of the ouput voltages is proportional to the sine of the angle displayed on the dials and the other is proportional to the cosine.

1-9. SYNCHRO MODE. In the synchro mode, the four wire output is converted to a three wire output in a Scott-tee transformer arrangement. The unit simulates the ideal 3-wire electrical output of a synchro control transmitter (CX). One of the three voltages is directly proportional to the sine of the angle displayed on the dials and the other two voltages are located 120° in amplitude from the first.

1-10. Because of their very low output impedance and extremely low output impedance unbalance, the standards may be operated under normal load with no degradation of accuracy. The angular accuracy is based on the use of toroidal transformers and therefore age or environmental conditions have little effect.

1-11. The following features are incorporated in the unit:

a. Quadrant or 100° increment switching to simulate operation over a full 360°.

b. Separate sets of binding posts for the synchro and resolver outputs.

c. Selectable output (E_S max).

d. Excitation of 115 or 26 vac.

TABLE 1-1. SPECIFICATIONS

Angular Range	0° to 360° continuous
Angular Accuracy	2 seconds-of-arc at nominal frequency
Angular Increments:	
*Model DSRS-3DR	0.001°
*Model DSRS-5DR	0.0001°
*Model DSRS-6DR	0.0001°
*Model DSRS-7DR	Degrees, Minutes, Seconds
Excitation:	
Voltage	115 or 26 vac
Frequency (DSRS-3R, -5R, -7R)	400 to 800 Hz
Frequency (DSRS-6R)	60 HZ
Output, E_S (MAX)	115, 90, 26, and 11.8 volts
Maximum Effective Output Impedance Unbalance:	
DSRS-3R, -5R, -7R	
115 and 90 volts	0.05 + j.005 ohms
26 and 11.8 volts	0.01 + j.001 ohms
DSRS-6R	0.15 + j.015 ohms
Size	19" w x 5-1/4" h x 15" d

*Models with a D suffix (DSRS-5D) include a direct readout of angular position.

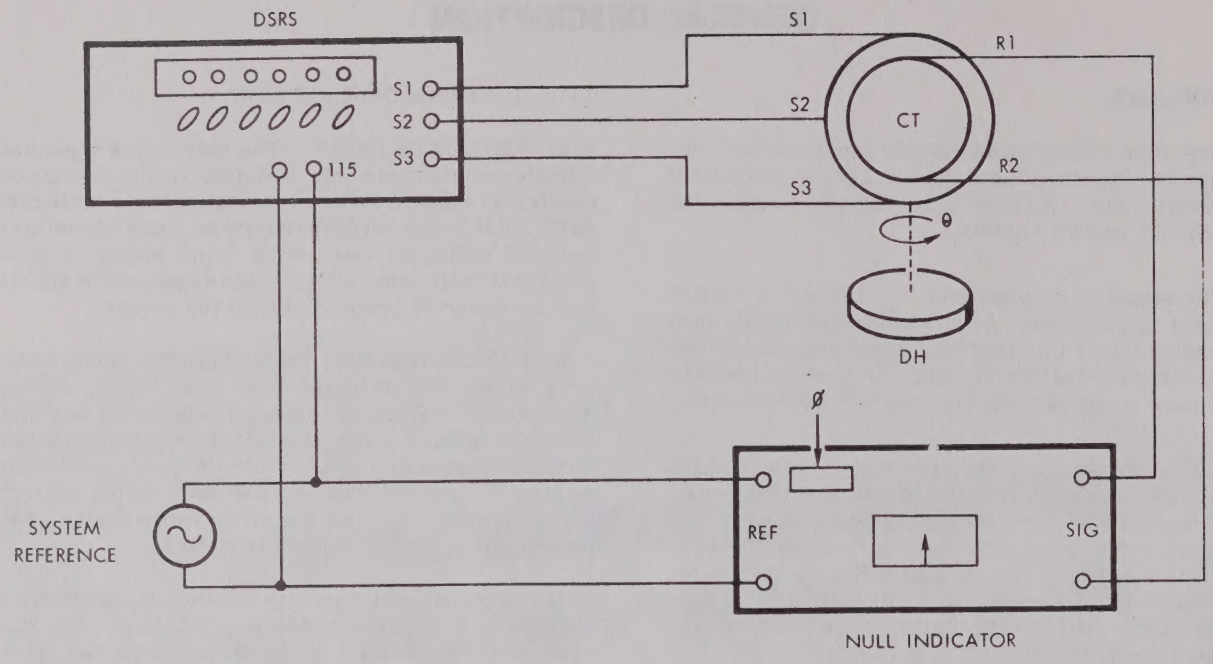


Figure 1-2. Typical Test Setup, Synchro Mode

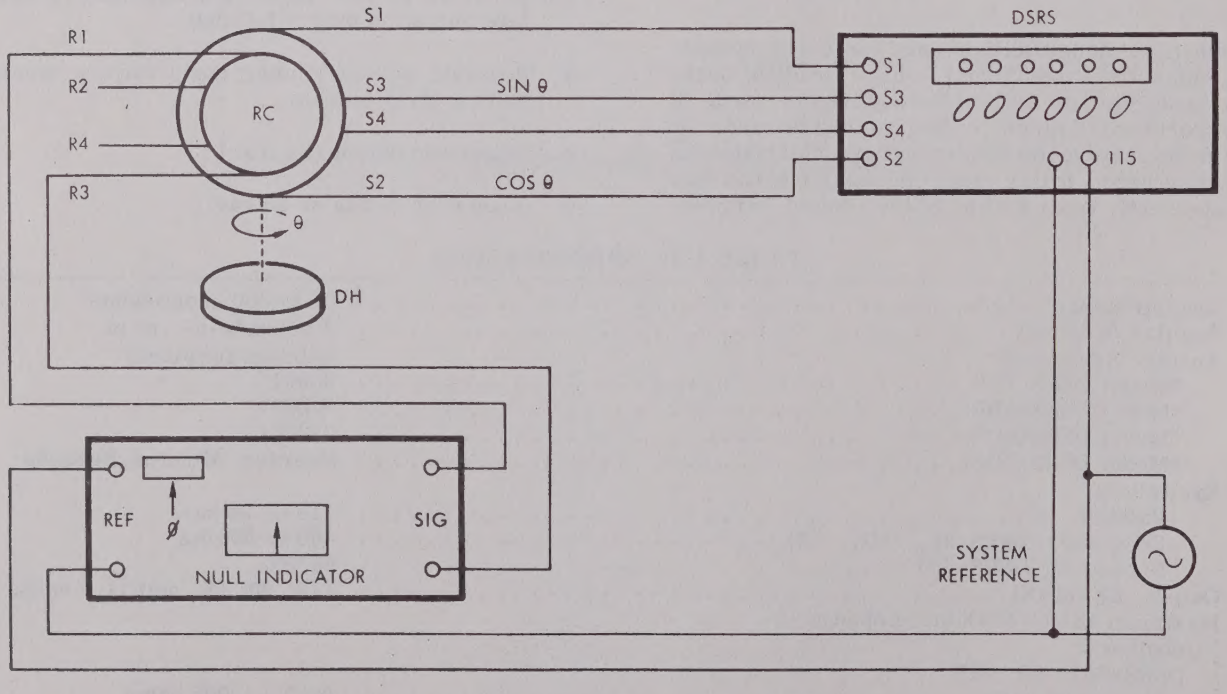


Figure 1-3. Typical Test Setup, Resolver Mode

SECTION II
INSTALLATION

2-1. UNPACKING.

2-2. No special handling or unpacking procedures are required. After unpacking, inspect units for any evidence of damage.

2-3. MOUNTING.

2-4. The unit is designed for standard 19 inch rack mounting.

2-5. OPERATING POWER.

2-6. No operating power is required, however either 115 or 26 vac excitation voltage is required during operation.

2-7. INSTALLATION CHECKOUT.

2-8. Refer to paragraphs 5-7 through 5-11 for a checkout procedure.

SECTION III
OPERATION

3-1. GENERAL.

3-2. SYNCHRO BINDING POSTS. The color coding of the synchro binding posts and the phase relations of the output voltage relative to input voltages conform to the requirements of Military Specification MIL-S-20708A. To convert the terminal identifications to the Aeronautical Radio, Inc. (ARINC) system, refer to table 3-1. The conversions given in the table apply for 0 degree index reference and positive rotation reference.

3-3. RESOLVER BINDING POSTS. The color coding of the resolver binding posts and the phase relations of the output voltage relative to input voltages conform to the requirements of Military Specification MIL-R-21530D.

TABLE 3-1. BINDING POST IDENTIFICATIONS, SYNCHRO MODE

COLOR CODE	IDENTIFICATION	ARINC SYSTEM
Red	R1	H
Black	R2	C
Blue	S1	X
Black	S2	Z
Yellow	S3	Y
White	Case Gnd	

3-4. SPECIAL PRECAUTIONS. To obtain maximum accuracy, observe the following precautions:

a. Always use high quality switches, with very low contact resistance, whenever it is necessary to switch the outputs.

b. Never fuse the outputs.

c. Do not purposely apply an unbalanced load.

d. Use No. 18 tinned copper wire from the output of the standard to the load and attempt to keep the total lead length from each output pin the same.

e. Stator current should be limited to approximately one ampere for normal switch contact life and should never exceed two amperes.

3-5. OPERATION.

3-6. To operate the standard, proceed as follows:

a. Set E_S (MAX) OUTPUT switch to desired maximum output voltage.

b. Set TYPE switch to appropriate position.

c. Connect system or unit under test to the appropriate set of OUTPUT binding posts.

d. Connect excitation voltage to the appropriate INPUT binding posts.

CAUTION

Do not apply 115 V to the 26 V INPUT binding post.

e. Set in the desired angle with the decade control switches.

SECTION IV
THEORY OF OPERATION

4-1. RESOLVER MODE.

4-2. The electrical position of a resolver transmitter can be determined from the ratio of the two output voltages to each other. One of the output voltages is proportional to the sine of the rotational angle and the second is proportional to the cosine. At 0°, the sine voltage is 0 and the cosine voltage is maximum. At 45°, the two voltages are equal and approach a 0.707 ratio to the maximum output voltage.

4-3. In the Model DSRS, a transformer is placed across the input voltage and functions as a dual voltage divider. The dual secondaries of the transformer are tapped to provide the voltage ratios of an ideal resolver at 10° increments. One secondary provides a voltage proportional to the sine of the selected angle and the second is proportional to the cosine.

4-4. RATIO TRANSFORMERS. (See figure 4-1.) The increased resolution of the decade increments is provided by two ratio transformers. Both ratio transformers are controlled by a common set of switches. Transformers T3, T5, and T7 provide the additional increments for the sine voltage and all sine voltage increments are added together to form the output voltage. Transformers T4, T6, and T8 provide the additional cosine increments and these increments are subtracted from the voltage supplied by transformer T2.

4-5. The cosine voltage, selected by contacts B and C of switch S2, supplies not only the 10° cosine increment but also supplies the input for the primary of transformer T3. The secondary of transformer T3 is tapped to provide voltage divisions corresponding to the tangents of the 1° increments. Contact A of switch S3 selects a COS X TAN voltage. In the example shown, this voltage is a COS 40° X TAN 5° product. The total voltage at contact A is the sum of the voltage selected by contact D of switch S2 (Sin 40°) plus the COS 40° X TAN 5° product. This total voltage may also be expressed as:

$$\frac{\text{SIN } (40° + 5°)}{\text{COS } 5°}$$

4-6. The two arms of switch S3 (A and B) supply a 1° sine voltage to transformer T5. This transformer is tapped to approximate the .1° sine increments. Contact A of switch S4 therefore selects a .1° sine voltage which is added to the voltage supplied from contact A of switch S3. The addition process continues until the final .001° voltage is selected by switch S6.

4-7. The cosine voltage is developed in approximately the same manner. Since the sine voltage input to transformer T4 is inverted, the voltages selected from the cosine ratio transformers are subtracted. In the example shown, the voltage on contact C of switch S3 is equal to COS 40° – SIN 40° X TAN 5°. This total voltage may also be expressed as:

$$\frac{\text{COS } (40° + 5°)}{\text{COS } 5°}$$

4-8. QUADRANT SWITCHING. The voltage ratios repeat every 90°; however, the mathematical signs of the ratios (+ or -) change for each quadrant. Switch S1 changes the signs by inverting the voltages.

4-9. INPUT CIRCUIT. Transformer T1 in the input circuit performs two functions: first it operates as an autotransformer to step-up a 26 volt input and second it corrects for variations in transformation ratio. In the method used to derive the sine and cosine voltages, the transformation ratio varies over any 10° increment. The input voltage is varied by a separate arm of switch S3 to compensate for this variation.

4-10. OUTPUT CIRCUIT. In the resolver mode, transformers T9 and T10 operate as step-down transformers to allow selection of the maximum output voltage, E_S (MAX). This selection is accomplished through switch S7.

4-11. SYNCHRO MODE.

4-12. The electrical position of a synchro control transmitter (CX) can be determined from the ratio of the stator output voltages to each other. As shown in figure 4-2, each of the three output voltages is a sine function.

4-13. The sine θ voltage, as derived in the resolver mode, is also used as the sine θ voltage for the synchro mode. To derive the other output voltages, transformers T9 and T10 are interconnected into a Scott-tee arrangement as shown in figure 4-3. The sine and cosine inputs to the transformers are derived in the same manner as for the resolver mode.

4-14. MINUTE AND SECOND INCREMENTS.

4-15. For a readout in minutes and seconds, transformers T5 through T8 (figure 4-5) are wound and tapped for minute and second increments.

4-16. DIRECT READOUT.

4-17. For a direct readout of angular position, the quadrant switch is replaced with a 100° increment switch as shown in figure 4-6.

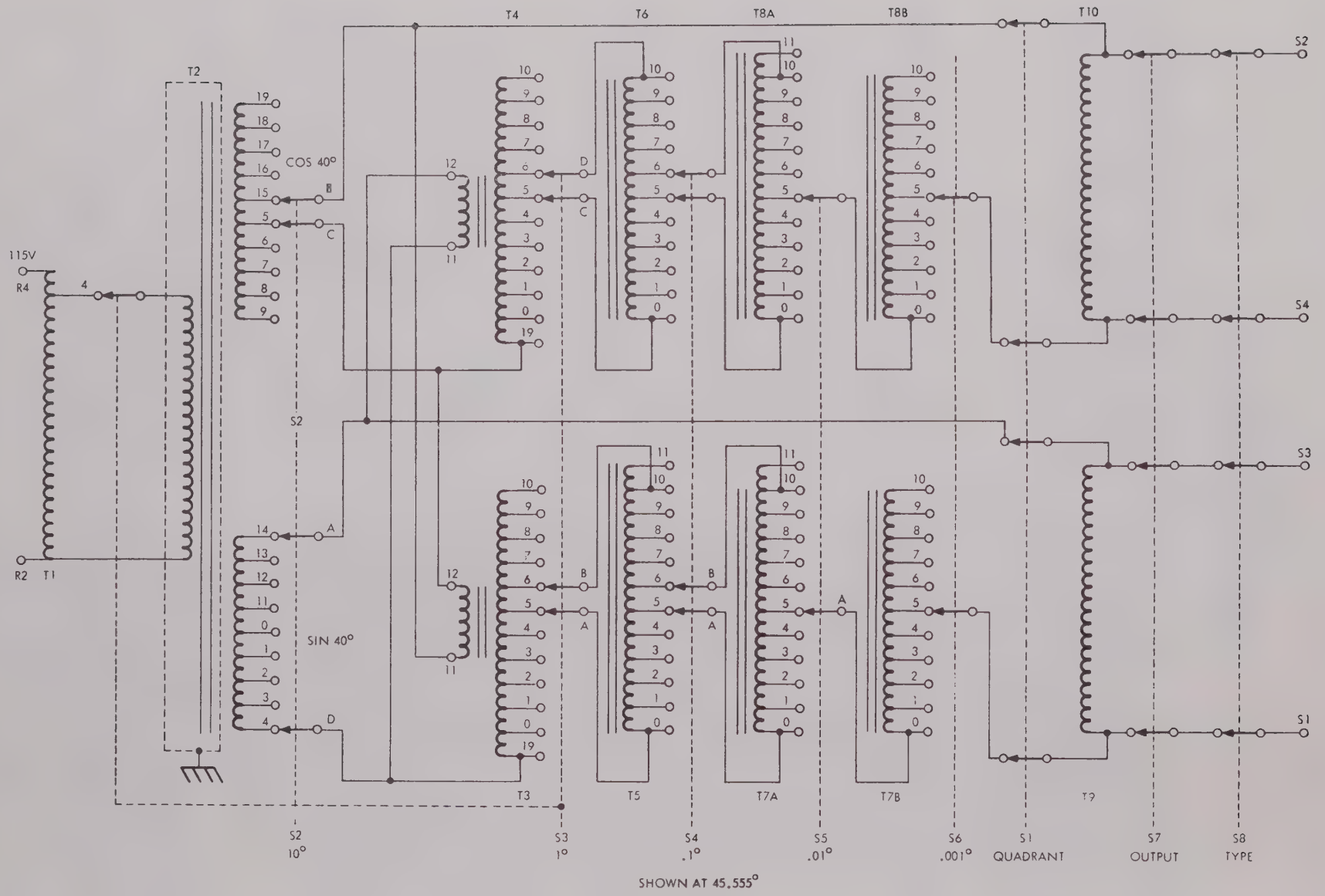


Figure 4-1. Simplified Diagram, Resolver Mode

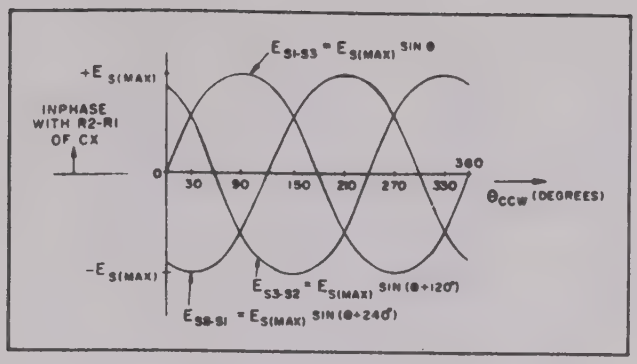


Figure 4-2. Standard Synchro Control Transmitter (CX) Outputs

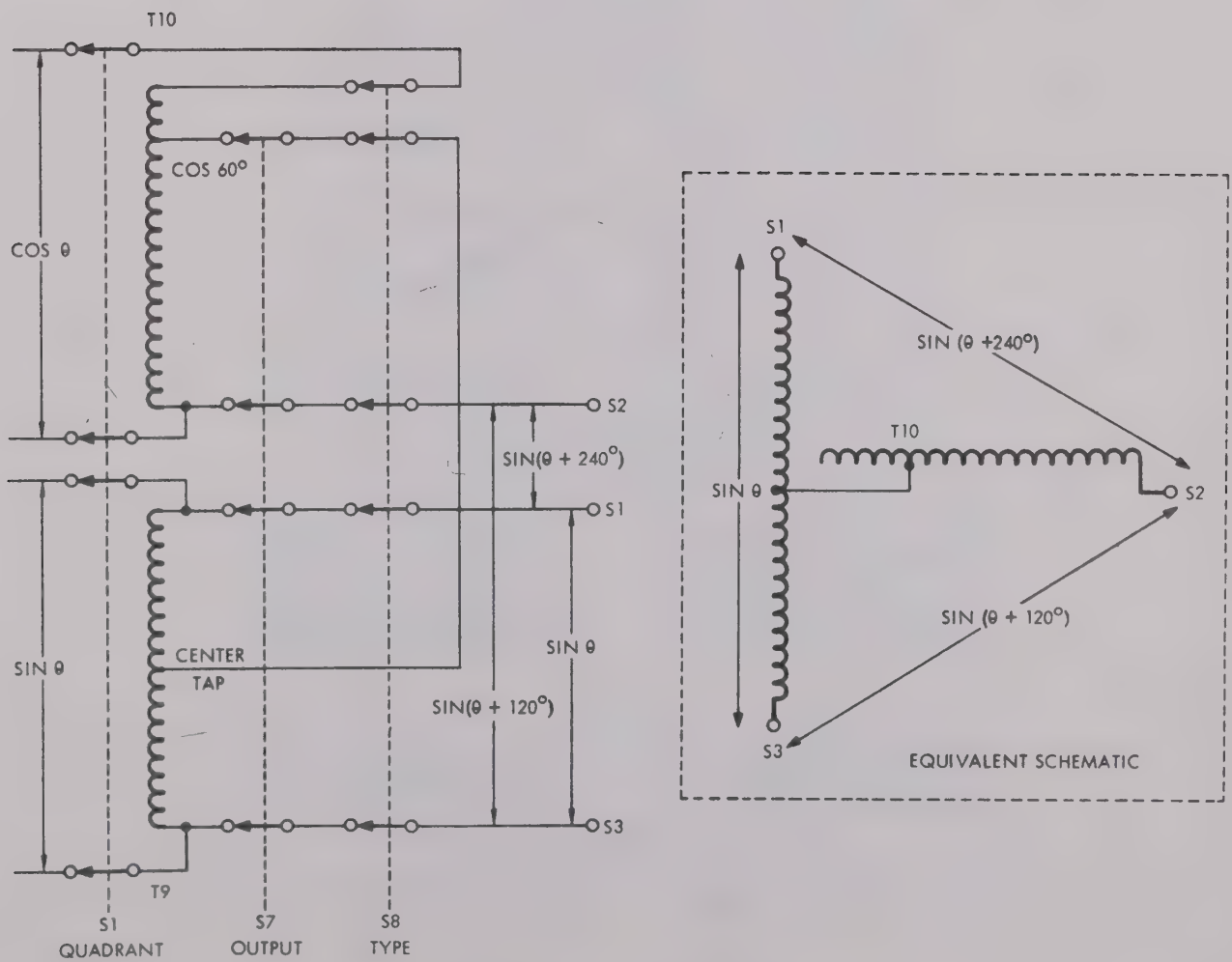


Figure 4-3. Simplified Diagram, Synchro Mode

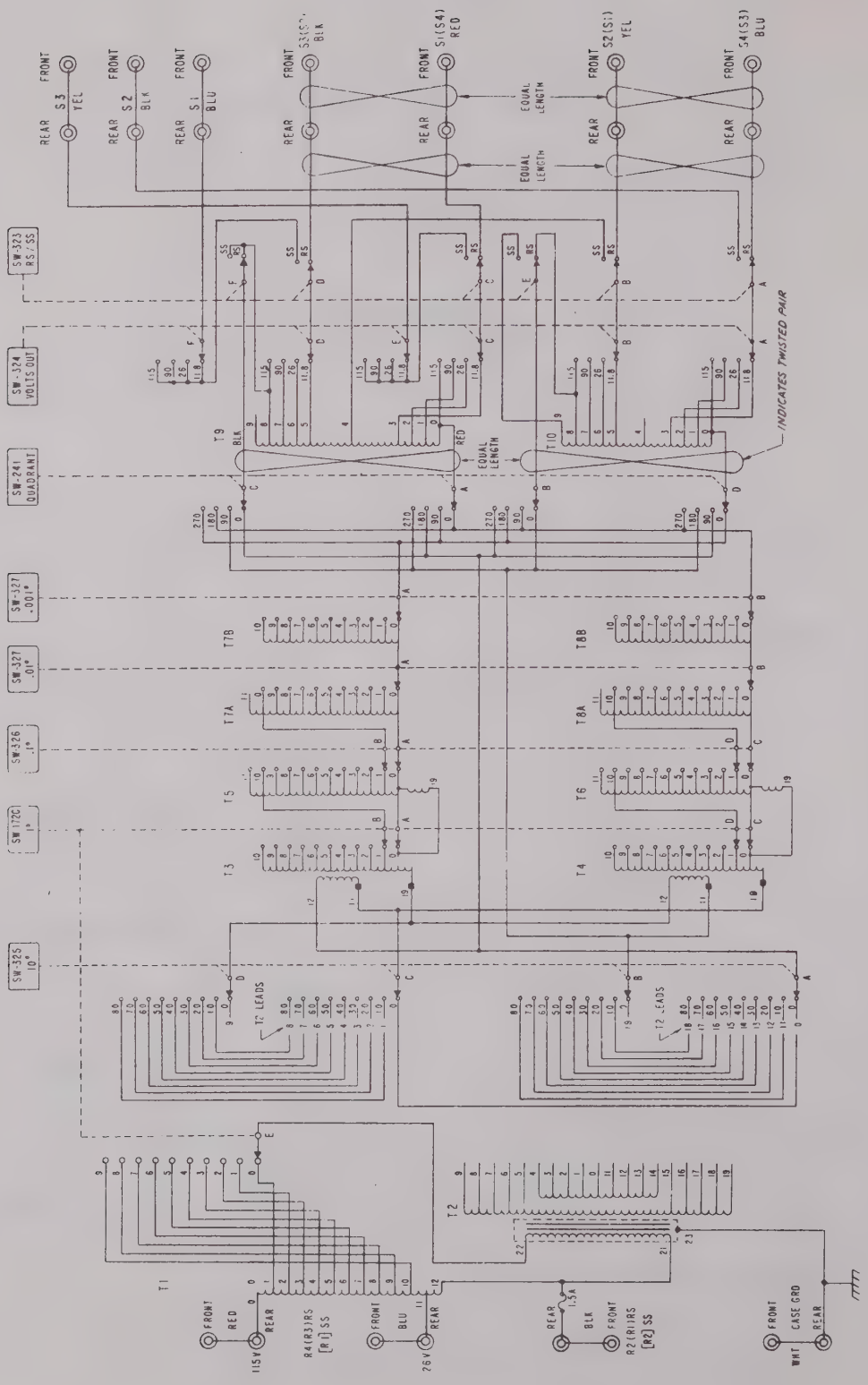


Figure 4-4. Model DSRS-3R Schematic Diagram

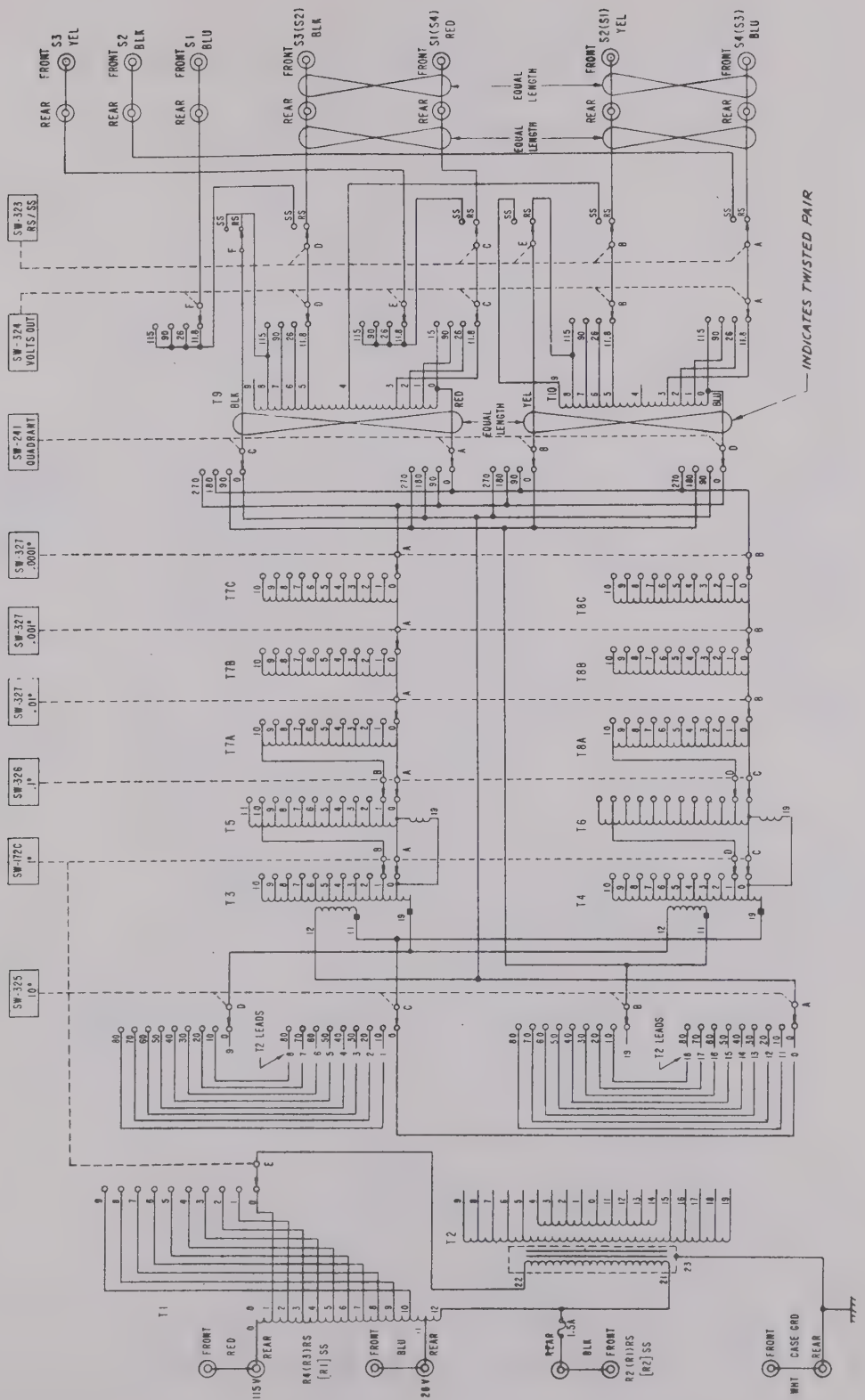


Figure 4-5. Model DSRS-5R Schematic Diagram

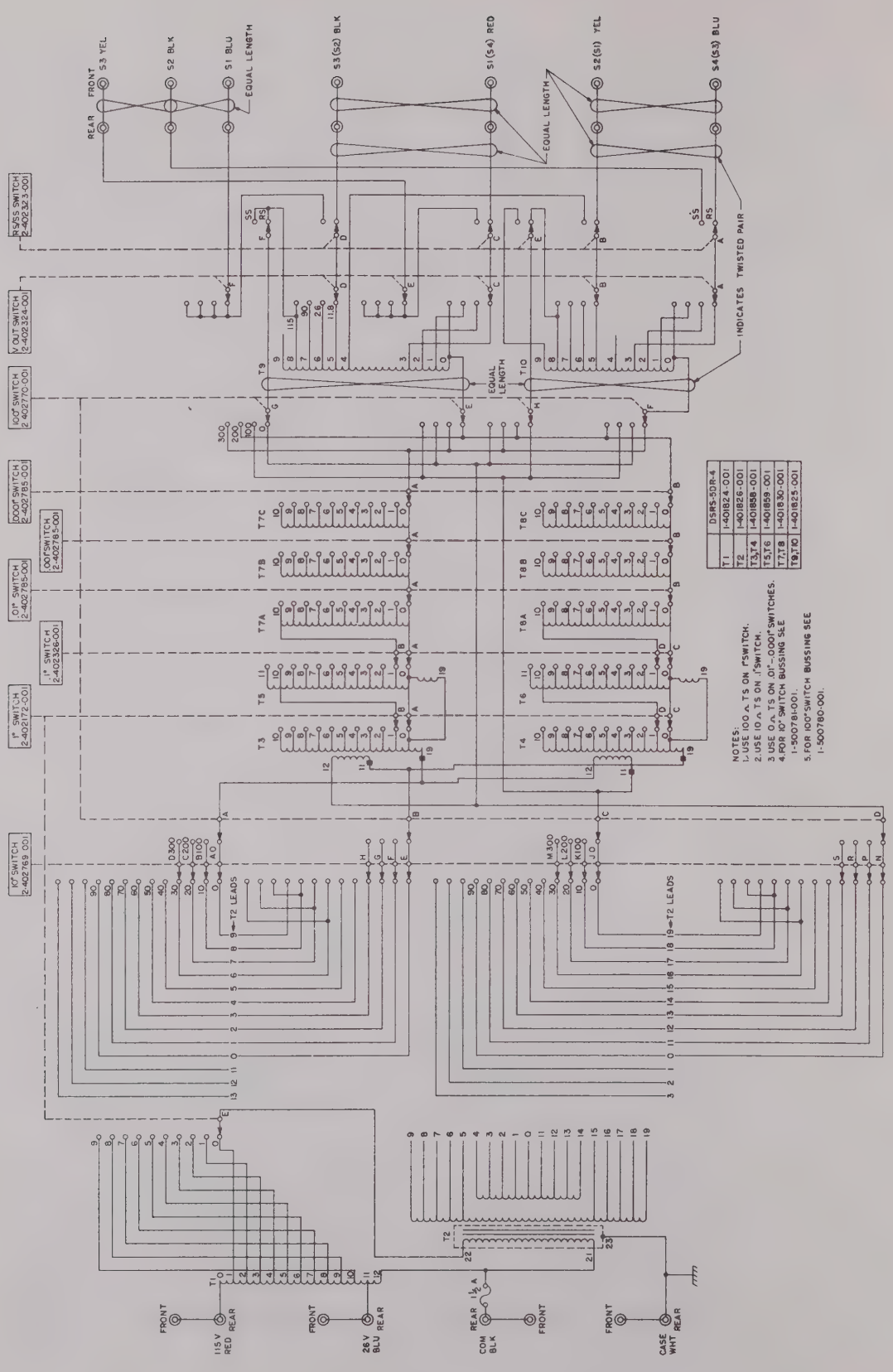


Figure 4-6. Model DSRS-5DR Schematic Diagram

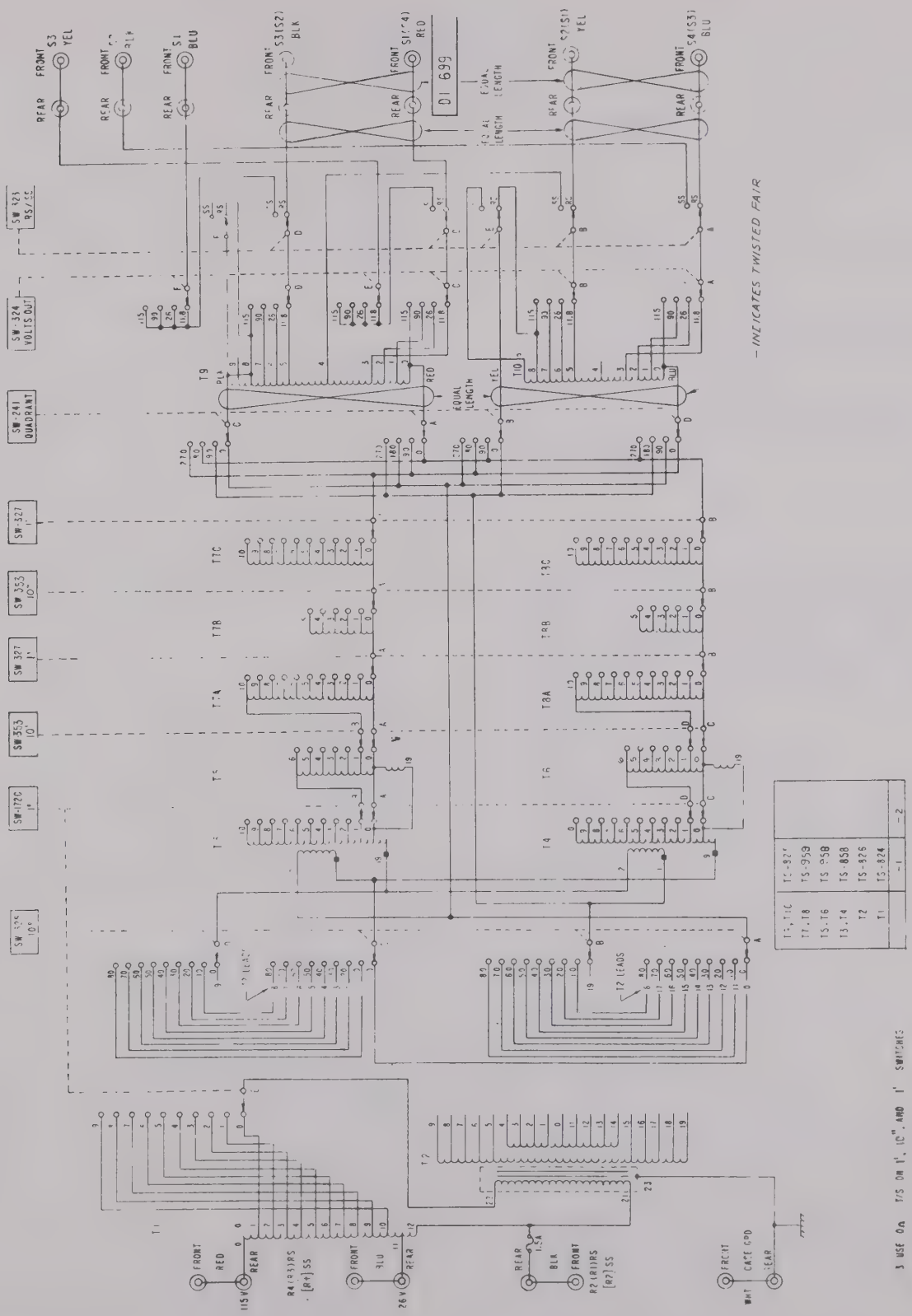


Figure 4-7. Model DSRS-7R Schematic Diagram

SECTION V
MAINTENANCE

5-1. GENERAL.

5-2. Since the standards are passive devices, a minimum of maintenance is required. With the exception of cleaning switch contacts, no maintenance on a regularly scheduled basis is required. Moving parts are lubricated at the factory and should require no further lubrication.

5-3. SWITCH.

5-4. Once every three to six months, clean switch contacts with a good grade of solvent such as alcohol or acetone. Relubricate contacts with a thin layer of vaseline.

5-5. REPAIRS.

5-6. If any repairs are made on the unit or if any parts are replaced, check the accuracy of the unit as outlined below. If any transformer problems are encountered it is recommended that the unit be returned to the factory for overhaul and recalibration.

5-7. CALIBRATION.

5-8. The accuracy of the standard should be maintained for a period of not less than three years, provided that the unit is kept in a normal laboratory environment, has clean low-resistance contacts and does not suffer injury or insulation damage. Under these conditions, the unit should only require calibration every three years. Under more severe conditions, the calibration period must be shortened.

5-9. TEST EQUIPMENT. To test the accuracy of the unit, the following test equipment (or equivalent) is required:

a. Phase Angle Voltmeter, Gertsch Model PAV. A phase-sensitive null indicator, such as Gertsch Model NI-5, may also be used.

b. Ratio Standard, Gertsch Model 1011.

5-10. ANGULAR ACCURACY, RESOLVER MODE. To test the angular accuracy of the resolver standard, proceed as follows:

a. Connect unit into test setup as shown in figure 5-1.

NOTE

Connect the ratio standard directly to the output terminals of the resolver standard to eliminate errors resulting from voltage drops in the interconnecting leads.

b. Adjust Phase Angle Voltmeter to measure in-phase voltage.

c. Set resolver standard to 0°.

d. Adjust ratio standard a. required to obtain a null on Phase Angle Voltmeter.

e. The ratio standard shall indicate an output ratio (A theoretical) of 0.000000 within the limits set by the A column of table 5-1.

f. Repeat test at every 5° increment between 0° and 360°. Refer to table 5-1 for the required output ratio and tolerances.

NOTE

The effective output impedance unbalance of the standard may be readily checked by applying a BALANCED load to the output and measuring A. When testing with an inductive load, it is recommended that non-ferromagnetic inductors (GR type 1482 or equivalent) be used to prevent output voltage variations from changing the inductance of the load.

g. Repeat test at the decade increments. Refer to table 5-2 for the required ratios and tolerances.

5-11. ANGULAR ACCURACY, SYNCHRO MODE. To test the angular accuracy of the synchro standard, proceed as follows:

a. Connect unit into test setup as shown in figure 5-2.

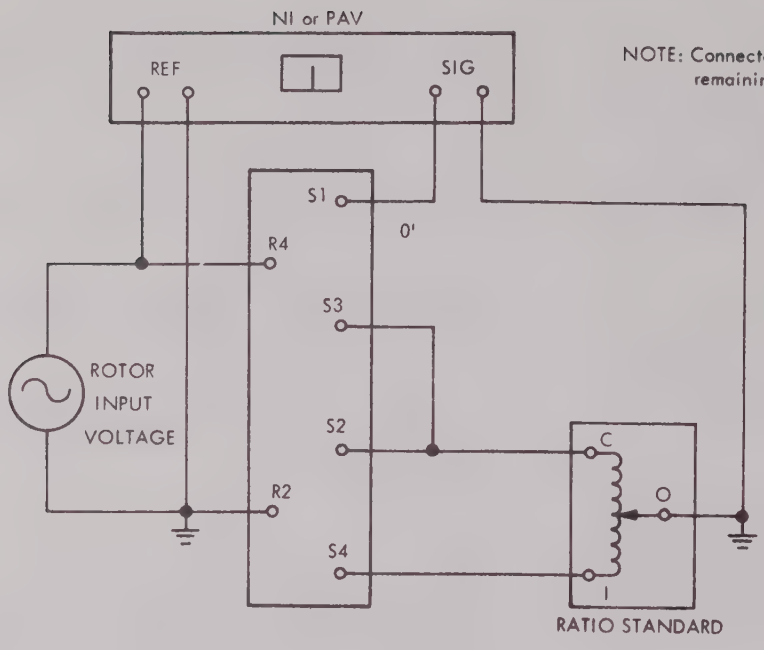
b. Adjust phase angle voltmeter to measure in-phase voltage.

c. Set the synchro standard to 0°.

d. Adjust ratio standard as required to obtain a null on the phase angle voltmeter.

e. The ratio standard shall indicate an output ratio (A theoretical) of 0.000000 within the limits set by A column of table 5-3.

f. Repeat test at the increments listed in table 5-3 (5-4 for minutes and seconds increments).



NOTE: Connected for measurements between 0° and 40°. For remaining measurements, connect as follows:

θ				
	0'	C	I	C
0° to 40°	S1	S2	S4	S3
45° to 85°	S4	S2	S1	S3
90° to 130°	S2	S3	S1	S4
135° to 175°	S1	S3	S2	S4
180° to 220°	S3	S4	S2	S1
225° to 265°	S2	S4	S3	S1
270° to 310°	S4	S1	S3	S2
315° to 355°	S3	S1	S4	S2

Figure 5-1. Angular Accuracy Test Setup, Resolver Mode

TABLE 5-1. ANGULAR ACCURACY, RESOLVER MODE

θ								$A_{theoretical}$	$\Delta A_{(ppm)}$
0		90		180		270		0.000000	9
5	85	95	175	185	265	275	355	0.087489	9
10	80	100	170	190	260	280	350	0.176327	10
15	75	105	165	195	255	285	345	0.267949	10
20	70	110	160	200	250	290	340	0.363970	11
25	65	115	155	205	245	295	335	0.466308	11
30	60	120	150	210	240	300	330	0.577350	13
35	55	125	145	215	235	305	325	0.700208	14
40	50	130	140	220	230	310	320	0.839100	16
	45		135		225		315	1.000000	19

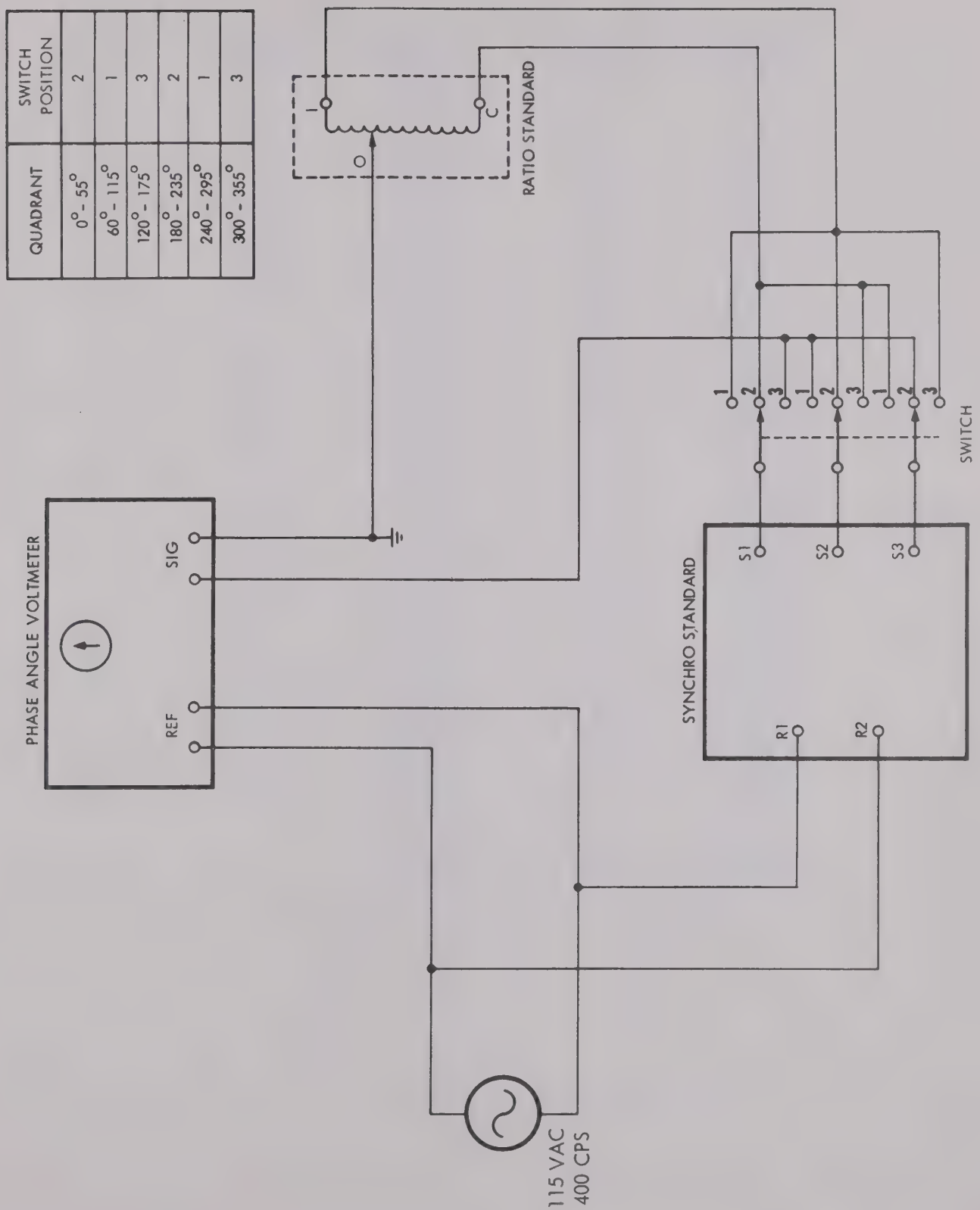


Figure 5-3. Angular Accuracy Test Setup, Synchro Mode

TABLE 5-2. ANGULAR ACCURACY, DECADE INCREMENTS, RESOLVER MODE

ANGULAR SETTING	THEORETICAL RATIO	MAXIMUM DEVIATION (±)
.001	.0000175	.0000097
.002	.0000349	.0000097
.003	.0000524	.0000097
.004	.0000698	.0000097
.005	.0000873	.0000097
.006	.0001047	.0000097
.007	.0001222	.0000097
.008	.0001396	.0000097
.009	.0001571	.0000097
.01	.0001745	.0000097
.02	.0003491	.0000097
.03	.0005236	.0000097
.04	.0006981	.0000097
.05	.0008727	.0000097
.06	.0010472	.0000097
.07	.0012217	.0000097
.08	.0013963	.0000097
.09	.0015708	.0000097

ANGULAR SETTING	THEORETICAL RATIO	MAXIMUM DEVIATION (±)
.1	.0017453	.0000097
.2	.0034907	.0000097
.3	.0052360	.0000097
.4	.0069814	.0000097
.5	.0087269	.0000097
.6	.0104724	.0000097
.7	.0122179	.0000097
.8	.0139635	.0000097
.9	.0157093	.0000097
1	.0174551	.0000097
2	.0349208	.0000097
3	.0524078	.0000097
4	.0699268	.0000098
5	.0874887	.0000098
6	.1051042	.0000098
7	.1227846	.0000098
8	.1405408	.0000100
9	.1583844	.0000100

TABLE 5-3. ANGULAR ACCURACY, SYNCHRO MODE

θ	$A_{theoretical}$	$A_{(ppm)}$
0	0.000000	11
135	0.267949	9
210	0.500000	8
345	0.732051	9

TABLE 5-4. ANGULAR ACCURACY, DEGREES, MINUTES, SECONDS INCREMENTS

ANGULAR SETTING θ	THEORETICAL RATIO (TAN θ)	MAXIMUM DEVIATION
1''	0000049	0.0000097
2''	0000097	0.0000097
3''	0000145	0.0000097
4''	0000194	0.0000097
5''	0000242	0.0000097
6''	0000291	0.0000097
7''	0000339	0.0000097
8''	0000338	0.0000097
9''	0000436	0.0000097
10''	0000485	0.0000097
20''	0000970	0.0000097
30''	0001454	0.0000097
40''	0001939	0.0000097
50''	0002424	0.0000097
1'	0002909	0.0000097
2'	0005818	0.0000097
3'	0008727	0.0000097
4'	0011636	0.0000097
5'	0014545	0.0000097
6'	0017453	0.0000097
7'	0020362	0.0000097
8'	0023271	0.0000097
9'	0026180	0.0000097
10'	0029089	0.0000097
20'	0058178	0.0000097
30'	0087269	0.0000097
40'	0116361	0.0000097
50'	0145454	0.0000097
1°	0174551	0.0000097
2°	0349208	0.0000097
3°	0524078	0.0000097
4°	0699268	0.0000097
5°	0874887	0.0000098
6°	1051042	0.0000098
7°	1227846	0.0000098
8°	1405408	0.0000100
9°	1583844	0.0000100
10°	1763270	0.0000100

SECTION VI
PARTS LIST

ITEM	PART NO.	MFR	DSRS-3	DSRS-3D	DSRS-5	DSRS-5D	DSRS-6	DSRS-6D	DSRS-7	DSRS-7D
Binding Post, Black	29-3 BLK	Grayhill	4	4	4	4	6	6	6	6
Binding Post, Blue	29-3 BLUE	Grayhill	8	8	8	8	4	4	4	4
Binding Post, Yellow	29-3 YEL	Grayhill	6	6	6	6	4	4	4	4
Binding Post, Red	29-3 RED	Grayhill	2	2	2	2	6	6	6	6
Binding Post, White	29-3 WHT	Grayhill	2	2	2	2	2	2	2	2
Fuse, 1-1/2 amp	MDL 1-1/2	Bussmann	2	2	2	2	2	2	2	2
Fuseholder	342004	Littelfuse	2	2	2	2	2	2	2	2
Knob	OP-1	Singer	6	6	7	7	7	8	7	8
Dial Assy, Quadrant	AW-912	Singer	1		1		1		1	
Dial Assy, Decade	AW-694	Singer	5	5	6	6	6	6	6	6
Switch, 90°	SW-241	Singer	1		1		1		1	
Switch, 100°	2-402770-001	Singer		1		1		1		1
Switch, 10°	2-402769-001	Singer	1	1	1	1	1	1	1	1
Switch, 1°	SW-172	Singer	1	1	1	1	1	1	1	1
Switch, 0.1°	SW-326	Singer	1	1	1	1	1	1	0	
Switch, 0.01, 0.001, 0.0001°	2-402785-001	Singer	2	2	3	3	3	3	0	
Switch, 10', 1', 10", 1"	SW-353	Singer	0	0	0	0	0	0	2	4
Switch, VOLTS out	SW-324	Singer	1	1	1	1	1	1	1	1
Switch, RS/SS	SW-323	Singer	1	1	1	1	1	1	1	1
Transformer Assy	TA-519	Singer	1	1	0	0	0	0	0	0
Transformer Assy	TA-520	Singer	0	0	1	1	0	0	0	0
Transformer Assy	TA-568	Singer	0	0	0	0	1	1	0	0
Transformer Assy	TA-572	Singer	0	0	0	0	0	0	1	1
Knob	AC-95	Singer	2	2	2	2	2	2	2	2

Synchro and Resolver Testing

by

Carl A. Sorensen
Project Engineer

Synchro and Resolver Standards

Prior to the introduction of synchro and resolver standards, "master" transmitters were simulated with an ordinary synchro or resolver transmitter together with an angular positioning device, a synchro or resolver bridge, a phase-sensitive null detector, a bridging transformer, and a phase shifter. This technique required the operator to "calibrate" the transmitter against the bridge at *each* angle by adjusting the angular positioning device for a null on the detector. The purpose of the phase shifter, required by both military and commercial specifications, was to compensate for the time phase shift of the transmitter. The main disadvantages of this technique are that it is relatively slow and inaccurate, besides being difficult to operate, expensive, and quite space consuming. The inaccuracy of this method is due to several causes, such as operator error, drift, hook-up error, plus the specified error of the individual pieces of equipment.

The requirement for an efficient and accurate "master" synchro and resolver transmitter was met by a simple extension of the time-proven *RatioTran** technique, pioneered by *Gertsch** over a decade ago. This device, which replaces all of the equipment required by the earlier technique, was soon termed a synchro or resolver standard. Basically, a *Gertsch* synchro or resolver standard consists of an extremely low phase shift transformer with a primary and one or two *isolated* secondaries respectively. The secondary has several precision taps which determine the angles available. Depending upon the particular model, angles may be selected by several techniques such as by turning one or more knobs, pulsing a rotary solenoid operated switch, or by energizing a relay.

Besides possessing a high degree of no-load accuracy (2 seconds-of-arc traceable to NBS) standards generally have a very low nominal output impedance, and an extremely low output impedance unbalance. This allows a normal load to be applied without significantly affecting the no-load accuracy. The output impedance of synchro and resolver standards is typically a few ohms; however, specific values of output impedance e.g., 50 + j50 ohms can be provided for applications where it may be desirable to actually simulate the output impedance of a synchro or resolver. In order to prevent angular errors due to loading from occurring, it is necessary for the output impedance of the standard to be balanced at each angular position. Output impedance unbalances as low as .01 + j.001 ohms are considered standard.

In addition to maintaining a high degree of accuracy under load, the standard may normally be operated over a wide voltage (10:1), and frequency range with very little degradation of accuracy. The frequency range of synchro and resolver standards extends from 30 cps to 10 KC or higher. Ideally, units are designed for a particular frequency; however, the useful frequency range for a particular unit generally extends to approximately two octaves (four times) above the design frequency. Operation below the design frequency will saturate the transformer, unless the input voltage is reduced in direct proportion to the frequency.

Normally, high accuracy resolver standard applications require that the outputs of the standard be isolated from each other. If the sine and cosine outputs of the standard are common, an unsymmetrical current will be forced to flow through the interwinding capacitance of the resolver under test; therefore, causing angular errors to occur which under actual conditions do not exist.

Synchro and Resolver Bridges

Basically there are two types of synchro and resolver bridges — the resistive (10K) and the inductive. Up until a few years ago, the resistive-type bridges were the only type of bridges available; however, the demand for higher input impedances, lower output impedances, and higher accuracies brought about another extension of the *RatioTran* technique — the inductive-type bridge. Actually, the term inductive-type is somewhat misleading, since the inductive-type bridge is normally operated in the vicinity of self-resonance. Therefore, the input impedance may be slightly capacitive, resistive, or slightly inductive. Obviously, the highest input impedance will be obtained at the resonant frequency.

Compared to resistive-type bridges, inductive-type bridges have an input impedance almost two orders of magnitude greater, and an output impedance approximately three orders of magnitude lower. The inherently high output impedance of the resistive-type bridge severely limits its application at high frequencies, since internal and external stray capacitances are more likely to alter the tapped ratios and the critical impedance balance of the four 10K resistors.

It is a fact that the input impedance of an inductive-type bridge is somewhat a function of voltage; therefore, it is difficult to maintain a real high degree of input impedance balance. However, it should be noted that the higher the input impedance, the less the effect of input impedance unbalance. In addition, $1/\sin 2\theta$ variations in input impedance unbalance are allowable without increasing the angular error.

Both the resistive and the inductive types of bridges are available either compensated or uncompensated. A compensated bridge has the same error voltage gradient at each angular position. Resistive-type bridges are compensated by using different resistive dividers at each angle, while the inductive-type are compensated with the use of a scaling transformer. The output impedance of the compensated resistive-type bridge is approximately four times higher than the uncompensated type.

An often overlooked accessory piece of equipment required for synchro and resolver bridges is a bridging transformer, when using a single-ended null detector. Grounding one terminal of the bridge output directly can cause apparent angular errors to occur. All *Gertsch* compensated bridges utilize a combination scaling and double-shielded bridging transformer. If a compensated resistive-type bridge is used, a bridging transformer with an input impedance of a megohm or more is required, otherwise the compensation will be affected due to loading. In addition, it may be necessary to use a bridging transformer which has been resonated, in order to prevent phase shift of the error voltage from the output of the resistive-type bridge.

Gertsch uses a unique resolver bridge circuit which provides two isolated and double-shielded inputs, plus an isolated and double-shielded output. In addition, the circuit employed is inherently compensated. Resistive-type 4-arm resolver bridges effectively interconnect the center taps of the two output windings of the resolver under test through a 2.5K ohm resistance which has no effect *if* the outputs of the resolver under test are balanced to each other.

Inductive-type bridges are ideally designed for a particular frequency; however, the useful frequency range generally extends from one octave below (one-half) to one octave above (twice) the design frequency. The frequency range of inductive-type bridges is from 30 cps to 10 KC, or higher. At frequencies below 1600 cps, input impedances as high as 800K are available. The input impedance obtainable at 10 KC is approximately 250K.

Another often-heard argument against resistive-type bridges is that 10K ohms is not a realistic load. In fact, the 10K ohm load can cause angular errors to occur which under actual conditions would never exist, since the load is normally quite inductive. This is particularly true when testing synchros and resolvers with a high output impedance. Testing under load is normally accomplished by simply connecting the actual load, e.g. a CT, in parallel with the input to the bridge. Therefore, if the load impedance is a few thousand ohms or higher the input impedance of the resistive-type bridge will alter the apparent load impedance seen by the component under test. The input impedance of the inductive-type bridge, however, can normally be neglected.

Ratio accuracies equivalent to 2 seconds-of-arc are easily obtained and maintained with inductive-type bridges, while 2 seconds-of-arc is quite difficult to maintain with resistive-type bridges due to aging, temperature coefficients, and accidental overloading. Overloading of a resistive-type bridge can be caused, for example, by accidentally shorting one of the stator input leads to one of the output terminals. Although an overload may not be sufficient to burn-out the bridge, it is quite possible to permanently change the tap ratios and the total resistance values of the four arms. A damaged bridge could go undetected for several months, until it's recalled for periodic "calibration."

Copyright 1963, by Gertsch Products, Inc. (An acquisition of The Singer Company, Metrics Division)

*A Trademark of THE SINGER COMPANY

Whichever type of resolver bridge is used, resistive or inductive, the user should be certain not to use the type of bridge which commons the sine and cosine outputs of the resolver under test, unless large angular errors can be tolerated. Such errors are a function of the source impedance and the interwinding capacitance of the resolver under test, neither of which are generally known by the bridge user. Therefore, it is best to avoid this type of bridge entirely.

High Resolution Standards and Bridges

Conventional 5° resolution standards and bridges are generally inadequate for servo system or module testing, where convenient values of system parameters (knots, yards, etc.) are not even multiples of 5°. In general, high-resolution (.001°) decade standards and bridges are used: (1) As a distinctly superior system-error bridge, for measuring the output angle of synchros or resolvers which are an integral part of a system or sub-system; (2) for trouble-shooting sources of error in data transmission systems such as cable loading, gearing, dial readout, impedance unbalance, etc.; (3) to generate precise input angles to a system or sub-system; (4) to measure system sensitivity or response to small angular errors; (5) for measuring the drift or stability of a system about a particular point.

The theory of operation of these *Gertsch* instruments is basically the same as the 5° units, except that several precision transformers and switches have been added to effectively multiply the number of taps by 5,000 in order to provide .001° resolution.

A very important feature of the *Gertsch* decade bridges is their complete independence of synchro or resolver functional accuracy, transformation ratio, and phase shift, plus their completely passive circuitry. Absolutely no preliminary calibration manipulations are required.

Functional Accuracy Testing

The angular accuracy of a data-transmission synchro or resolver is based on the *ratio* of two output voltages to each other. The functional accuracy of a computational resolver, however, is based on the ability of each output winding, individually, to produce a voltage proportional to the sine or cosine of the shaft angle. The output 90° from minimum coupling is normally used as the reference voltage.

The procedure for measuring functional accuracy consists of setting up a voltage across a voltage divider which is equal in amplitude and phase to the output of the winding under test at 90° from minimum coupling. The output of the resolver at each angle is then bridged against the output of the voltage divider. A computational resolver with a functional accuracy of 0.05% would be allowed ± 500 ppm deviation from the theoretical sine or cosine value at each angle. Note, that the allowable *angular* error is a function of the angular position of the shaft. For example, a 0.05% functional error corresponds to an angular error of 1.7 minutes at 0°, and 3.4 minutes at 60°.

In practice, the above technique may be instrumented in either one of two ways. The first technique employs a Sine θ *RatioTran* (sine 0° to 90° in 5° steps), a Phase Angle Voltmeter (PAV), a conventional *RatioTran*, and an RC phase shifter. The functional error at each angular position is displayed on the PAV as an error voltage. For example, a 0.05% computational resolver with a maximum output of 15V, is allowed ±7.5 mv at *each* angular position. With the variable range attenuator on the PAV, 7.5 mv can be set up to read full-scale on the 3 mv range. Therefore, the functional error at each angle can be read directly on the PAV meter.

The second technique utilizes a *Gertsch* Complex Ratio Bridge (Model CRB-2B) and a conventional *RatioTran*. The *RatioTran* is adjusted for a null on the CRB with the resolver set to 90° from minimum coupling. The inphase *RatioTran* on the CRB is adjusted for a null at each angle, and its deviation from the theoretical sine or cosine of the shaft angle is noted in ppm. The quadrature *RatioTran* at null, can be set up to indicate the phase shift from primary to secondary, directly in degrees.

Automatic Testing

Gertsch developed two lines of automatic synchro/resolver standards and bridges, the rotary solenoid type and the relay (programmable) type. Basically the rotary solenoid type is ideal for component angular accuracy tests, since the unit sequentially advances in 5° steps with each contact closure. On the other hand, the relay type is ideal for system testing where random access to several angles may be desired. Input commands can be in several forms such as BCD, straight binary, decimal, etc.

To accompany the rotary solenoid type units in automatic component tests, *Gertsch* developed an automatic dividing head. This automatic unit advances 5° every six seconds, and remains there for approximately 4 seconds. In addition to automatically advancing itself, it also advances the rotary solenoid standard or bridge, mutes the phase angle voltmeter, and lowers the pen on the DC recorder at the proper moment. The timing sequence for this remote control is programmed by cam-operated switches. The camshaft is driven from the same synchronous motor that drives the 5° indexing mechanism.

With the automatic test set-up above, it is possible to complete a 72 point angular accuracy test in less than 10 minutes including set-up time. If a strip chart recorder is used, a permanent record of the components error can also be made automatically. Manual techniques can take as long as an hour or more — even with an experienced operator.

Dividing Heads

Unlike most other test instruments used in angular accuracy tests, not all dividing head errors can be measured, or specified. The most common specification for dividing heads is the indexing accuracy. Indexing accuracies currently available range from 20 seconds-of-arc down to ¼ of a second-of-arc. Additional errors depend upon the way in which the component under test is mounted in the dividing head, and the environmental conditions. An ideal mounting technique is one which causes absolutely no end or radial loading of the rotor relative to the stator.

Some dividing head manufacturers employ a mounting technique which rigidly clamps the rotor and the stator of the component under test to the dividing head. It is extremely difficult for an average skilled operator to mount a component in this type of dividing head without causing any radial and/or end loading due to misalignment. An extremely important precaution which must be taken with this mounting technique is to make sure that all mounting surfaces are entirely free from dirt. In fact, it is almost a requirement that this type of dividing head be operated in a dust-free room. In addition, unless the component under test is geometrically perfect, i.e., there is no eccentricity in the rotor, the rotor axis is perpendicular to the mounting surface of the stator, etc., several seconds or possibly minutes-of-arc error can be created.

The *Gertsch* mounting technique consists of rigidly clamping the rotor, and effectively floating the stator. The only precaution that the operator must take is to be careful not to apply physical force to the component through the wires attached to the stator.

Phase Angle Voltmeters

The Phase Angle Voltmeter (PAV) is ideal for synchro and resolver angular accuracy tests, since an external phase shifter is not required in order to compensate for the time phase shift angle of the component under test. In addition, large amounts of quadrature (fundamental null) can be tolerated without affecting the accuracy of the inphase null.

The *Gertsch* PAV has several features designed to aid synchro and resolver angular accuracy testing. For example, when using the "Proportional Voltage Gradient Method" 3 minutes-of-arc may correspond to, say, 19.6 mv. However, with the variable attenuator on the front panel of the PAV, 19.6 mv can be set up to equal full scale deflection on the 10 mv scale. Thus, the angular error at each 5° point can now be read directly on the 3-0-3 scale of the PAV. Other features include plug-in, ±5% band-pass, filters from 50 cps to 10 KC, DC recorder output (±37.5 mv equals full scale on meter), optional meter relay plug-in to provide contact closures at + and − full scale deflection, variable reference angle from 0° to 360° continuously, variable attenuator — any voltage from 1 mv to 300V can be adjusted for full scale deflection, high quadrature rejection — overload lamp lights when the total input signal exceeds 10 times the range selector position.

Synchro and Resolver Specifications

Synchro and resolver specifications have made good progress in the last few years. Before that, resolver specifications were, for all practical purposes, non-existent. The worst result of this was the confusion generated for several years by not having a set of *standard* equations relating input and output voltages to each other, as a function of shaft position.

The Polaris resolver specification Mil-R-21530 (D) was the first universally accepted publication covering both data-transmission and computational type resolvers. Shortly thereafter, a *draft* copy of Mil-S-22347 (data-transmission resolvers only) was issued which agreed with Mil-R-21530's equations; however, a few months later Mil-S-22666 (computational resolvers only) came out, and disagreed with Mil-R-21530's equations. As a result, there is general agreement on the equations for data transmission type resolvers, and some disagreement on computational types. Mil-R-21530's equations would have been the easiest to standardize upon, since it specified the same equations for both types of resolvers. Incidentally Mil-S-22347 has never been released, although the draft was written three years ago.

The SAE specification ARP-461 (A) covers both data-transmission synchros and resolvers, and is in general agreement with all other specifications. An ARP computational resolver specification is in process, and the B revision to ARP-461 is well under way.

The specification Mil-S-20708 (B) (data-transmission synchros only) was recently revised with several minor refinements, one of which was to define the impedance Z_m.

Synchro and resolver standards, and inductive-type bridges are widely used for both military and commercial applications. In fact, a large number of these instruments are presently used in the most advanced guidance and fire control systems. However, neither the military or the commercial specifications have been brought up-to-date in this respect, even though these units have been in use for several years. The currently available specifications show only the obsolete "master" transmitter techniques, and the resistive-type bridges. The requirement for revising the current specifications is obvious, since at present there are no specifications which show what the values and tolerances of the various electrical parameters associated with these new units should be, and which circuit configurations are acceptable.

Future Trends

For obvious reasons, size 8 (approximately 0.8" in diameter) is fast becoming the most popular size component for new designs. Soon after that the trend will probably be toward size 5 components. With this trend toward smaller size components, will come a requirement for dividing heads which cause less and less radial and end loading.

Components with higher accuracies will of course become available; resolvers with one second-of-arc accuracy are not too difficult to imagine. Higher impedance values, and higher frequencies will also become more common.

The Hall-effect synchros and resolvers may go into production in a few years, assuming that the temperature sensitivity and output voltage limitation problems are solved. With them will come smaller sizes, lower voltages, and wider frequency ranges (D.C. to megacycles).

Major improvements in test equipment design are most likely to occur in the high frequency and high resolution area; however, major improvements in other areas such as dividing heads are also quite probable. It should be pointed out though that the test equipment available today is still several steps ahead of the majority of components currently available.

REFERENCES AND BIOGRAPHY

1. *An Analysis of Synchro and Resolver Bridges;* Carl A. Sorensen, Project Engineer; First Edition 1-19-62; Fourth Edition 1-15-63.
2. *ARINC Synchro System Manual* and *ARINC Synchro Signal Practices;* Reports No. 407 and 407-1; Combination Reprinted June 1, 1961; Aeronautical Radio, Inc.; 1700 K St., N.W., Washington 6, D.C.
3. *Characteristics of Testing and Applications of Electrical Resolvers;* A Special Projects Office Publication (Dept. of the Navy); Code Ident. 10001 OD 23404; 8 March 1962.
4. *Military Specification;* Synchros, 60 and 400 Cycle; General Specification; MIL-S-20708B; 1 Jan. 1963.
5. *Military Specification;* Synchros, Resolver; Data Transmission General Specification; MIL-S-22347 (WEP); Draft Dated 1 March 1960.
6. *Military Specification;* Synchros, Resolver; Computing; General Specification; MIL-S-22666; 1 Nov. 1960.
7. *Military Specification;* Resolvers, Electrical, AC; For Use In Polaris Fleet Ballistic Missile Weapon System; General Specification For; MIL-R-21530D (WEPS); 26 Feb. 1962.
8. *Precision Synchro and Resolver Test Instruments Plus Theory and applications;* Catalog No. 11, Third Edition; 11-15-62.
9. *Proceedings, Synchro Design and Testing Symposium;* 17 and 18 March 1960; Held at the Department of Commerce Auditorium; Sponsored by Department of the Navy, Bureau of Naval Weapons, Washington, D.C.
10. *Resolver Handbook;* Reeves Instrument Corporation; Roosevelt Field, Garden City, New York; RICO Bulletin No. 57; Copyright 1954.
11. *Resolver Manual;* American Electronics Incorporated, Instrument Division; 1598 East Ross Avenue, Fullerton, California; July 1959.
12. *Servomechanism Practice;* W. R. Ahrendt, and C. J. Savant, Jr., Ph.D.; Second Edition; McGraw-Hill Book Company, Inc., New York; 1960.
13. *Synchros* (Commercial Specification); Aeronautical Recommended Practice; Society of Automotive Engineers, Inc.; 485 Lexington Ave., New York 17, New York; ARP 461A; Issued 7-1-55, Revised 11-15-59.
14. *Synchro and Resolver Evaluation and Test Equipment;* Staff Report; Electro-Technology; A Conover Mast Publication; May 1963.
15. *Technical Information For The Engineer;* Servo Motors, Tachometer Generators, Motor Generators, Synchros; Kearfott Division, G. P. I.; Little Falls, New Jersey; Seventh Edition, Revised 9-1-61.
16. *The Servo Engineer's Handbook;* Daystrom Transicoil. Division of Daystrom, Inc.; Worcester, Montgomery County, Pennsylvania; Fourth Printing, September 1959; Library of Congress Catalog Card Number: 59-15182.
17. *United States Navy Synchros, Description and Operation;* A Bureau of Ordnance Publication; OP 1303 (First Revision); 15 April 1958.

APPENDIX II

APPLICATION DATA

TESTING DATA-TRANSMISSION SYNCHROS AND RESOLVERS FOR ANGULAR ACCURACY

GENERAL

The function of data-transmission synchros and resolvers is to transmit angular position from one physical location to another via three or four wires. Synchros have the advantage over resolvers in that one less wire is required; however, it is more difficult to manufacture high accuracy synchros, because of their more complex winding configuration.

DEFINITION — ELECTRICAL ERROR

The angular accuracy of a data-transmission synchro or resolver is briefly defined as the difference between the mechanical position and the electrical position. This difference, expressed in angular units, is referred to as the Electrical Error of a synchro or resolver.

CONTRIBUTING ERRORS

Electrical Error is a result of the combined affect of several measurable errors. The following parameters are all possible contributors:

1. Transformation ratio unbalance.
2. Variation in phase shift.
3. Null spacing error.
4. Inter-axis error.
5. Functional error.

The above parameters are normally not tested individually for data-transmission synchros and resolvers, since it is only the affect that they have on the Electrical Error that is of importance. Note, that is is possible to have a large Functional Error and zero Electrical Error, if the *ratio* of the output voltages to each other is perfect.

By analyzing an Electrical Error curve, a manufacturer can determine the manufacturing errors:

TABLE I

Types of Electrical Error Curves Resulting From Various Manufacturing Errors.

Type of Error Curve	Manufacturing Errors
One cycle	Rotor eccentricity
Two cycle	Stator out-of-round. Unbalanced interwinding capacitance.
High Frequency	Design, since stator and rotor must be made up of laminations having a discrete number of slots.

ELECTRICAL ERROR SPECIFICATION

There are two ways of specifying Electrical Error: (1) *Maximum error* and (2) *Error spread. Maximum error* is the maximum positive or negative Electrical Error, measured over a full 360° of shaft rotation. Depending upon the origin of the error curve, it is possible to obtain two different interpretations of *maximum error*. Military specifications state that the origin of the error curve shall be at EZ, as shown in figure 1 (solid-line curve).

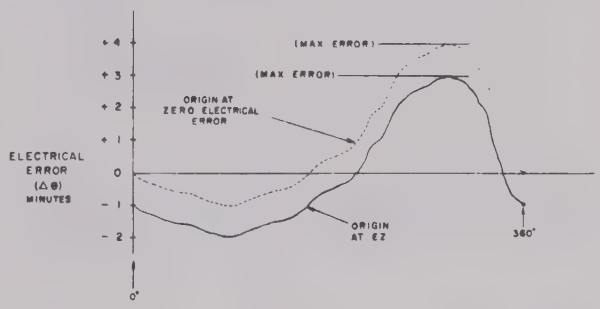


FIGURE 1. *Error Curves With Origin at EZ, and With Origin at Zero Electrical Error.*

Note, that is is possible for a synchro or resolver to have an Electrical Error at EZ. The *maximum error* for the solid-line curve shown is 3 minutes; however, if the origin is chosen at zero Electrical Error, the *maximum error* is equal to 4 minutes. The latter technique is, of course, the simpler and is used whenever possible.

The *error spread* is the sum of the maximum positive and maximum negative errors. Regardless of where the origin is chosen, the *error spread* is the same. Therefore, the origin should always be chosen at zero Electrical Error, since the test procedure is simplified. In the above example, the *error spread* is 5 minutes. As a rule-of-thumb, the *error spread* is approximately equal to 1½ times the *maximum error* from EZ.

ELECTRICAL ZERO

All Electrical Error tests are started at the approximate electrical zero (EZ) point. Coarse EZ of synchros and resolvers is usually indicated by a scribed radius on the exposed shaft end, which is lined up with an arrow stamped on the stator.

This EZ alignment procedure does *not* indicate that the unit will have the proper output phase relationships when the shaft is rotated in either direction. This so-called phasing test is actually performed during the Electrical Error test. If the unit under test and the test instrument must be rotated in opposite directions, the phasing is incorrect.

The following diagrams illustrate the phase relationships at EZ, for the different types of synchros and resolvers:

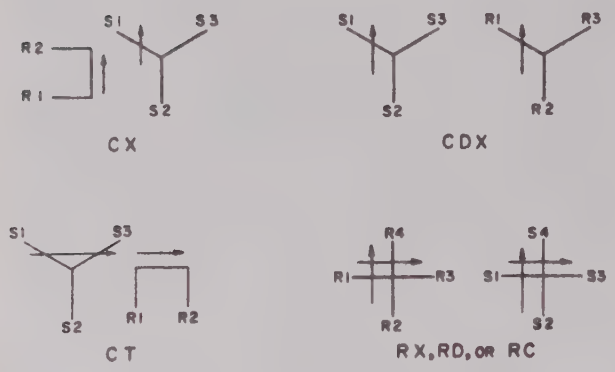


FIGURE 2. *Synchro and Resolver Phase Relationships at EZ.*

TEST CIRCUITS

The procedure for measuring Electrical Error requires either a Synchro/Resolver Standard or a Bridge, as specified in the following table:

TABLE II

Test Instruments Required for Electrical Error Measurement of Various Units.

Type of Unit to be Tested	Test Instrument Required for Electrical Error Measurement			
	SYNCHRO STANDARD	SYNCHRO BRIDGE	RESOLVER STANDARD	RESOLVER BRIDGE
CX		X		
CDX (stator)	X			
CDX (rotor)		X		
CT	X			
RX				X
RD (stator)			X	
RD (rotor)				X
RC			X	

Circuits for the above tests are illustrated in the SS, SB, RS, and RB sections of this catalog. The R1 and R3 leads shown in the CDX (rotor) and RD (rotor) test circuits may appear to be reversed. This reversal, however, is necessary in order to provide an *increasing* angle to the bridge as the shaft angle is increased. This is a direct result of the fact that differentials *subtract* from the angle applied to their input as their shaft angle is increased (rotated CCW as viewed from the shaft end), if R1 is connected to S1 and R3 is connected to S3 of a control transformer.

TEST METHODS

Two test methods exist for measuring Electrical Error: (1) Proportional Voltage Nulling Method, and (2) Proportional Voltage Gradient Method. Both methods are described in military specifications.

The Proportional Voltage Nulling Method requires the use of the Dividing Head vernier for obtaining an exact null on the Phase Angle Voltmeter. The Electrical Error at each position is then read on the vernier dial.

The Proportional Voltage Gradient Method is several times faster than the nulling method. Since the error voltage gradient of a control transformer, or a control differential transmitter (rotor) is the same at each angle, and is linear for quite a large angular error ($\triangle\Theta = 5°$ causes only .13% error), it follows that the Electrical Error can be read directly in terms of voltage. A Phase Angle Voltmeter with a variable range control is very advantageous for this application, because any *maximum error* may be adjusted to correspond to full-scale deflection. Therefore, it is possible to record Electrical Error at each angle as a percentage of the maximum permissible Electrical Error, or directly from the calibrated scale if the selected full-scale Electrical Error is a multiple of 1 or 3.

The Phase Angle Voltmeter is calibrated by, first, obtaining a null with the Dividing Head vernier, and then purposely introducing (with the vernier) the exact amount of Electrical Error, desired to correspond to full-scale. Next, the variable range control on the PAV is adjusted for full-scale deflection, and the vernier is *then* returned to the null position. The test is performed by advancing the Dividing Head and the Bridge or Standard, in 5° steps, 72 times. At each 5° step the Electrical Error is displayed on the Phase Angle Voltmeter.

It should be noted that a *compensated* Synchro or Resolver Bridge must be employed when using the Proportional Voltage Gradient Method to test control transmitters, or control differential transmitters (rotor).

IMPORTANCE OF ϕ

The reference axis for the phase-sensitive detector must be along the inphase output axis of the synchro or resolver. Otherwise, a portion of the fundamental null voltage (V_Q) will appear to be a part of the inphase output signal. As an example, consider a typical 26V CX with an $E_{S(max)}$ of 11.8V:

Fund. Null (V_Q) = 20MV
Phase Shift (ϕ) = 10°

If the input axis is chosen as the reference axis, a small amount of signal voltage is required to cancel the portion of V_Q which is "inphase" with the input.

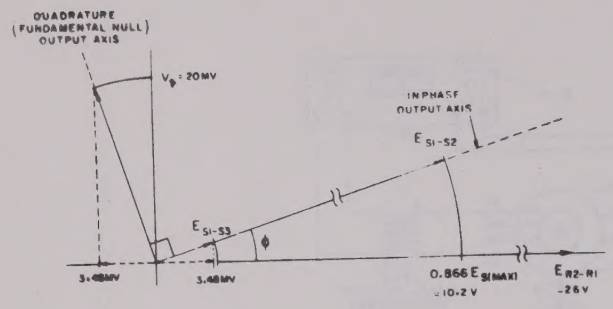


FIGURE 3. *CX Outputs Near EZ.*

As can be seen from figure 3, the amount of signal voltage (E_{S1-S3}) necessary is:

$$E_{S1-S3} = \frac{20 \times \sin 10'}{\cos 10'} = 3.54 \text{ MV}. \qquad (1)$$

This corresponds to a value of θ equal to:

$$\theta = \sin^{-1} \frac{3.54\text{MV}}{11.8\text{V}} \cong 1' \qquad (2)$$

Therefore, the angle of the CX is approximately one minute from actual EZ.

A rule-of-thumb frequently used for specifying fundamental null voltage is that it shall be less than 50% of the maximum permissible Electrical Error in terms of voltage. The error voltage gradient of the CX in the above example is:

$$\frac{\Delta V}{\Delta \theta} = 11.8 \sin 1' = 206 \text{ MV/degree} \qquad (3)$$

Therefore, the approximate permissible *maximum error* of the CX in the example above is:

$$\Delta\theta = \frac{2 \times 20 \text{ MV}}{206 \text{ MV/degree}} \cong .2' = 12' \qquad (4)$$

Total null is, as a rule-of-thumb, allowed to be 50% greater than the fundamental null. This would amount to 30MV in the above example.

$\frac{\Delta V}{\Delta \theta}$ MAGNITUDE AND PHASE

The magnitude of the error voltage gradient $\frac{\Delta V}{\Delta \theta}$, or the "sensitivity" can be calculated from the equations in the following table for various error-sensing devices.

TABLE III

Error Voltage Gradient Equations for Various Error-Sensing Devices.

Error-Sensing Device (Stator Input / Rotor Output)	Error Voltage Gradient $\left(\frac{\Delta V}{\Delta \theta}\right)$, or "sensitivity"		
	Volts/Degree	MV/Minute	μV/Second
CDX (stator),*	$.0151NE_{S(max)}$	$.252NE_{S(max)}$	$4.20NE_{S(max)}$
CT*	$.0174E_{R(max)}$	$.291E_{R(max)}$	$4.85E_{R(max)}$
SB,**	$.0174NE_{S(max)}$	$.291NE_{S(max)}$	$4.85NE_{S(max)}$
RB**	$.0174E_{R(max)}$	$.291E_{R(max)}$	$4.85E_{R(max)}$
RD (stator), RC	$.0174NE_{S(max)}$	$.291NE_{S(max)}$	$4.85NE_{S(max)}$
	$.0174E_{R(max)}$	$.291E_{R(max)}$	$4.85E_{R(max)}$

* The transformation ratio (N) of a CDX or CT, as defined by Mil-S-20708A, is equivalent to the rotor voltage at maximum coupling divided by 0.866 $E_{S(max)}$.

** Gertsch Compensated Synchro and Resolver Bridges have a transformation ratio (N) of 1.000. Note, that an SB with an N of 1.000 is equivalent to a CT with an N of 1.155.

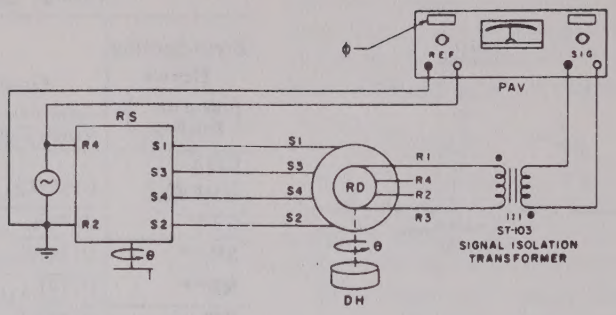
By observing the phase of the error voltage (ΔV) relative to the reference voltage, it can be determined whether the equivalent angular position of the input signal to the error-sensing device (θ_{elect}) is greater than, or less than, the angular position of the error-sensing device (θ_{mech}).

TABLE IV

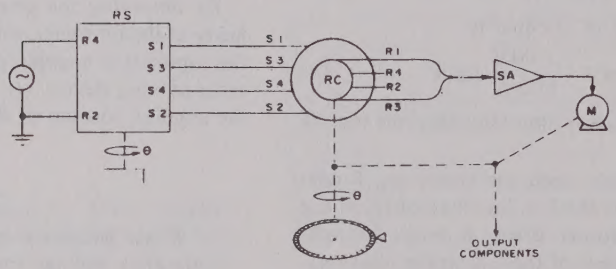
Phase Relationship Between Error Voltage and Reference Voltage for Various Error-Sensing Devices.

Error-Sensing Device	θ_{elect} greater than θ_{mech}
CT, SB	ΔV_{R2-R1} out-of-phase with E_{R2-R1}
CDX (stator)	ΔV_{R3-R1} out-of-phase with E_{R2-R1}
RD (stator), RB, RC	ΔV_{R3-R1} inphase with E_{R2-R4}, or ΔV_{R4-R2} inphase with E_{R3-R1}

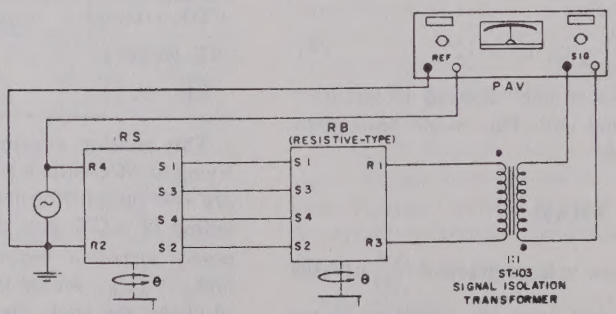
This phasing information is extremely important when trying to differentiate between true-null and false-null which are 180° apart. For example, if an SB is connected to the output of a CX, and the angle of the SB (θ_{mech}) is purposely *increased* beyond null, θ_{elect} is less than θ_{mech} and ΔV_{R2-R1} should be *inphase* with E_{R2-R1}. If it is out-of-phase, the angle displayed on the SB is 180° from the true angular position of the CX.



RD (stator) (or RC) Angular Accuracy Test. Note, that either the "Proportional Voltage Nulling" or the "Proportional Voltage Gradient" method may be used.



Using an RS as a "Dummy Director" to Position a Single-Speed Servo.



Calibrating Lower-Precision Resistive-Type Resolver Bridges. Note, that the error voltage from the RB may be converted to an equivalent angular error